(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
31 December 2003 (31.12.2003)

PCT

(10) International Publication Number
WO 2004/000115 A1

(51) International Patent Classification[7]: A61B 5/0476

(21) International Application Number:
PCT/NZ2003/000124

(22) International Filing Date: 19 June 2003 (19.06.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
519662 19 June 2002 (19.06.2002) NZ

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(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

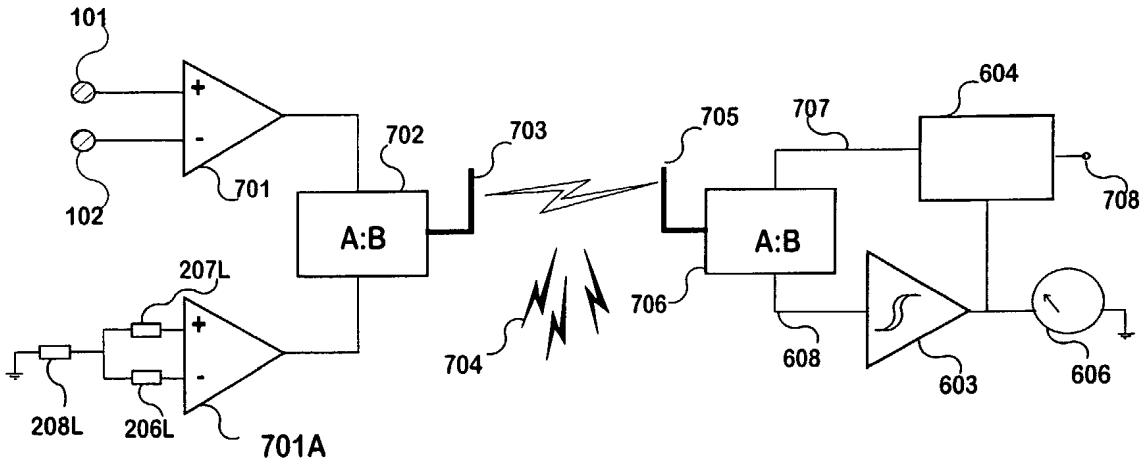
(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for the following designations AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW, ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG,*

[Continued on next page]

(54) Title: ARTEFACT REMOVAL DURING EEG RECORDINGS



(57) Abstract: A device for display and analysis of EEG signals collects artefact signals in a separate signal path and uses them after processing to clean up the EEG. Duplication of amplifier, cable and electrodes and use of an equivalent (dummy) input load provides an artefact channel for collecting electromagnetic inerference from the area including the patient, and triboelectric signals from patient signal cables. Impedance of any electrode lead may be continuously monitored for rapid impedance changes known to be causes of artefacts. Software may provide corrective messages to a user.

WO 2004/000115 A1

ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG)

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for the following designations AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW, ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG)*

— *of inventorship (Rule 4.17(iv)) for US only*

Published:

— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

TITLE ARTEFACT REMOVAL DURING EEG RECORDINGS

FIELD

This invention relates to medical and veterinary diagnostic apparatus; more particularly the invention relates to electrode design and signal processing apparatus using electrophysiological signals from part of a mammal in order to determine condition and prognosis. In particular, though not solely, the invention refers to electroencephalography (EEG) and records made by that technique.

BACKGROUND

Clinical assessment of patient status often makes use of recording of the EEG (electroencephalogram - typical signal level 10 microvolts) or the ECG (electrocardiogram- typical signal level of interest 100-500 microvolts). Especially for long-term recordings, reliable signals are useful. When EEGs are taken by non-specialist persons over long periods of time from infants or adults in intensive care, the output recording is liable to include many inadvertent and erroneous measurements as a result of the unintended inclusion of artefact signals of various origins in the event signal of interest. We are particularly interested in neonatal infant EEG recordings.

As used herein the term 'artefact' denotes all non-event signals that contaminate the event signal of interest. As will be appreciated by those skilled in the art, the precise nature and relative effect caused by any artefact signals will vary depending on the nature of the measuring instrument, the status of the patient, and the environmental conditions under which the measurements are taken.

Typically a measurement instrument handles a measured signal comprised of the event signal of interest (which is usually available at a very low level only) along with a variable artefact component related to one or more non-event signals. There are (a) externally generated artefacts, such as from electromagnetic fields, (b) patient-generated artefacts, such as signals from biological activity other than that being measured, and (c) equipment-generated artefacts such as those caused by noise, current fluctuations or overloading as well as mechanical artefacts, such as (d) caused by impact upon signal cables (connector noise, tribo-electric or microphonic effects) and (e) those caused by a shift of the electrode upon the underlying skin, as when the patient lies upon an electrode. In our own work we have been relatively unconcerned by eye effects - blink reflex or electro-oculogram (EOG) signals, or transfer of the electrocardiogram, because the preferred sampling area lies toward the back of the head. Artefacts attributable to external or environmental noise arise from electrical interference, amplifier clipping, incorrect electrode impedance, and AC mains "hum". Examples of hum include mains leakage, imbalanced three-phase loads; harmonic currents of the mains frequency induced in any conductors as a result of coupling by magnetic fluxes or earth loops; switching and

lightning-caused transients; diathermy/electrocautery machines, cellular telephones, computers, photonic interference and other sources of high-frequency interference; static electricity; aliasing; telemetry; salt bridges; and supply line transients. Another application is in brain function assessment during and after open-heart surgery where diathermy, use of imaging machines, and general handling of the patients are likely to cause artefacts. Artefacts may be brief or continuous.

A hospital ward includes most of the above artefact sources and is an imperfect location for EEG recording, especially over a long period and where a neonatal patient requires continual care and frequent handling. A long head cable is required, so that the EEG device can be kept out of the sterile incubator. The signal is of very low amplitude and may fall further in certain disease processes.

The inventors are interested in making reliable EEG recordings in ordinary intensive-care wards by people without specialist skills and over a long period. People not especially trained in EEG techniques are required to make long-term EEG recordings, a task more difficult as the patient becomes worse. More severely brain-injured infants often show a low level of EEG activity and may exhibit much physical movement resulting in more artefacts so are more likely to be falsely diagnosed from a long-term EEG recording, made in order to assess the infant's chance of recovery. The inventor's preferred devices include processes to derive evidence for seizures and to condense raw EEG data into a summarised form, both of which may be erroneous if interference is present.

The presence of artefact signals presents a potentially life-threatening problem by significantly corrupting the measured EEG signal so that it may not be relied upon as an accurate representation of the event signal, even though the raw EEG signal is converted into an abstract form (typically, spectral edge values). In any electrophysiological recording, the appearance of an unrecognised non-event signal in a record collected within a patient monitoring device could result in a clinician making an incorrect decision with respect to a patient's treatment, or, for devices that use algorithms to make decisions, could result in the device itself making an incorrect assessment of the patient's condition.

The problem to be solved can be stated as "the need to recognise and exclude, on a continuous basis, corrupting signals from within an electrical signal (EEG) being collected from a patient". This problem becomes more urgent as the patient's brain function decreases.

Prior art in this general area, apart from ad-hoc solutions such as use of screened rooms, falls into several groups. Carim et al, (US 6032060) condition the skin under a silver/chloride / gel electrode by passing a current through the skin to lower the impedance (unsuitable for neonatal infants). Taheri (US 6434421) provides a skin electrode including a dielectric layer like a "supercapacitor" to reduce current flow. Sherwin (US 4678865) reduces triboelectric effects by coating the insulator of the screened signal-carrying wires with graphite. Marro (US2002/0161309) reduces signal pickup by using optical transfer (and optical powering to active components upon an electrode array) while

a large number of articles report on the use of short-path radio-frequency links). WO/02/41774 Henning provided many simultaneously amplified sets of electrodes (all on the skin) upon an EEG electrode array and subtracts some resulting signals from a desired channel in order to electrically focus on a desired part of the brain. Greenwald et al (US 6032072) also use separate sets to identify "near-field" such as EEG and "far-field" such as EMG and EOG signals. John (US4846190) took 2.56 second samples from various sets of EEG electrodes and checked their content for signals resembling muscle action potentials or electrical transients. This invention would subtract noise from one epoch from signals in another epoch. Greenwald et al (US 5792069) filter cardiac artefacts from an EEG signal and replace them with adjacent normal portions of the EEG signal. Aspect Medical Systems (brochure dated 2002) describe a forehead electrode array including an above-eye electrode sensor of eye-related artefacts and other types such as electrocautery artefacts. None describe a "equivalent" or unconnected circuit within an electrode array.

OBJECT

It is an object of the present invention to provide improved apparatus and methods for the detection of externally generated artefacts during electrophysiological recordings, or at least to provide the public with a useful choice.

STATEMENT OF INVENTION

In a first broad aspect, the invention provides a device for assessment of a status of a mammal which monitors electrophysiological signals developed within the body of the mammal; the device including in functional connection a first signal path including at least one contact electrode, a first electrode circuit, first electrode coupling means, first signal amplification means, first signal processing means, and output means for presenting a useful first output to an assessor, wherein the device provides means for rejection of at least some interfering signals likely to interfere with the electrophysiological signals, the rejection means including means having a separate functional (second) signal channel for continuously monitoring the environment of the mammal, including the environment occupied by the device near the mammal being monitored in order to detect said interfering signals, and means for deletion of said interfering signals from the electrophysiological signals prior to presentation at the output means, so that the output after modification may be relied upon to a greater extent as a true indication of the status of the mammal being monitored.

Preferably, usable assessment procedures are selected from a range including: EEG (electroencephalogram); EMG (electromyogram); ECG or EKG (electrocardiogram), including fetal ECG; EOG (electrooculogram); and cranial impedance.

Preferably the device is particularly adapted for monitoring, over a long period, electrophysiological signals developed within the brain of the mammal so that the state of the brain of the mammal may be presented; the signals may be indicative or predictive of secondary phase brain damage.

Preferably the signals (whether actually present or not in the first signal path) are deleted by interruption of the EEG during the presence of the artefact signal in the second signal path.

Optionally the second or artefact signal is subtracted from the first or patient signal within an analogue or a digital signal processing stage, so that the artefact is deleted from the patient signal.

Preferably the second signal is used to control a gate capable of passing or blocking the first signal, so that the first signal is blocked during a period when an artefact is present.

Alternatively the second signal is taken to a decision machine capable of evaluating the amplitude of the second (artefact) signal during an epoch and setting an output accordingly, so that the epoch may be accepted or rejected accordingly, so that the output of the device is made substantially free of at least some artefacts capable of disturbing a procedure of recording an electrophysiological signal.

In an alternative aspect, the invention provides an electrode array including a set of electrodes for the recording of electrical signals originating within a mammalian patient, **wherein** the set of electrodes is laid down in desired positions upon a flexible substrate; the electrode array includes an equivalent circuit capable of at least partially simulating the passive electrical properties of the patient; the equivalent circuit being positioned close to at least some of the set of electrodes; the electrode array further includes conducting means connected to the equivalent circuit, similar to and alongside the conducting means used in relation to the set of electrodes, leading to connecting means capable of releasably connecting both the set of electrodes and the equivalent circuit to signal processing means.

Preferably the set of electrodes is disposable.

In a second broad aspect, the invention provides means for continuously monitoring the environment in terms of electromagnetically radiated interfering signals likely to be picked up within the body of the mammal, or a bed, or the signal cables, and so interfere with the electrophysiological signals, the means including (a) a second electrode circuit placed in proximity to the first electrode circuit, thereby comprising an electrode assembly, and (b) second electrode coupling means (e.g cable or other data link) used to couple the second electrode circuit to (c) a second signal amplification means, the output of which is connected to (d) signal removal means capable of removing said interfering signals from the first output at about the occurrence of said electromagnetically radiated interfering signals.

Usefully this second circuit is capable of responding to internally carried (abnormal) interference within the device, such as transients carried within power supply conductors or earth loops - including earth loops extending to the patient's bed.

Preferably the second electrode circuit is substantially electrically isolated from the body of the mammal and includes at least one selected electrical component connected to a second amplifier input; the at least one component being selected so as to simulate a typical electrical impedance presented to the first electrode circuit by the body of the mammal, when being monitored.

Preferably the second electrode circuit is intended for use with the usual symmetrical input (instrumentation) signal amplification means and includes three electrical resistances; one in series with each input, connected together at a common junction to a reference input through a third resistance, so as to simulate (as referred to an amplifier input) the typical electrical properties of the body of the mammal being monitored.

Preferably the equivalent circuit presents to the signal processing means a similar impedance to that presented by the patient to the patient signal processing means.

More preferably the equivalent circuit presents a higher impedance than that presented by the patient with freshly applied electrodes.

In an embodiment suitable for electroencephalogram (EEG) recording from the head of a neonatal or preterm infant, the preferred equivalent circuit comprises (a) a resistance of between five and 50, or more preferably about 30 kilohms attached between each of the two inputs of the signal processing stage, and a common junction, and (b) a resistance of about 10 times the magnitude of the input resistances (or more preferably about 150K ohms) connected between the common junction and the patient reference lead. (These values assume a chlorided silver skin electrode rather than a stainless-steel subcutaneous needle, for which the values would be higher.)

Optionally the properties of the resistance network are rendered more closely similar to the electrical properties of the patient as contacted through at least one skin or needle electrode by provision of capacitative reactance and/or inductive reactance.

Preferably the physical position of the equivalent circuit is close to at least one of the active electrodes.

Optionally the second electrode circuit may be electrically connected to the body of the mammal and for example it may be situated so as to collect "natural" artefact signals such as the electro-oculogram (EOG) and muscle action potentials from the heart (ECG), or eyelids or other voluntary muscles.

Optionally the second circuit may comprise a set of accessible electrodes against which a gel-coated conductive surface may be placed, to better simulate a mammalian body.

Optionally one or more motion sensors incorporated into the second electrode circuit may be used to detect patient movement.

Preferably the electrode assembly, including any electrical components, is supported upon a flexible electrode substrate material, including examples such as "Mylar" (TM) sheet, and appropriate fabrics.

In a third broad aspect, the invention provides means to detect mechano-electrical (triboelectric) interference to the cable, likely to interfere with the electrophysiological signals; the detection means including a second electrode circuit placed in proximity to the electrode assembly and coupled through a substantial replica of the first electrode coupling means, placed in close proximity to the first electrode coupling means, to a second signal amplification means, coupled to a signal removal means capable of removing said mechano-electrical (triboelectric) signals from the first output at about the time of occurrence of said signals.

Preferably, in the case of use of a wireless version of coupling from an electrode assembly to an external device, (rather than conductive cables as a communicating link to couple the electrodes to signal processing means), detection means for recognising artefact signals polluting the wireless transfer process includes a second electrode circuit placed in proximity to the electrode assembly and coupled through a substantial replica of the first wireless electrode coupling means to a second signal amplification means, coupled to a signal removal means capable of removing said electromagnetic interference signals from the first output at about the time of occurrence of said signals.

Optionally a second wireless channel may be generated without being based upon a simulated electrode array in a second electrode circuit as previously described within this section.

In a fourth broad aspect, the invention provides an impedance-based sensor of likely artefacts originating at an electrode as a result of change of electrical impedance when connected to the body of the mammal, wherein the assembly includes (a) means for continuously monitoring the electrical impedance, (b) means to identify any abrupt change in the electrical impedance as an indication of likely concurrent artefact, and (c) means to exclude the bio-electrical signal at about the time when an abrupt change in the electrical impedance is detected, so that an accompanying artefact may be excluded from analysis.

Preferably the means for continuously monitoring the electrical impedance comprises injection of a small alternating-current test signal into the circuit at a frequency high enough to be separable from the electrophysiological signals after amplification within bio-electrical signal processing means, measuring the resulting voltage, and identifying any abrupt change in the voltage, thereby providing the separate functional signal channel previously mentioned in this section.

In a fifth broad aspect, the invention (if based on digital computation) provides software capable through an output device of providing notification to an operator or assessor that describes the amount of artefactual rejection activity in existence, and advises at least one appropriate remedy in the case of an undesirable amount of artefacts.

Preferably the programme includes means to at least partially recognise one or more forms of artefact signal according to criteria, and to interrupt the first signal path during occurrence of said artefact signal, and to provide upon a display device information alerting an assessor to the nature and extent of the artefact signal, so that a relatively untrained assessor may take steps to reduce and adverse effect of the artefact signal.

PREFERRED EMBODIMENTS

The description(s) of the invention to be provided herein together with the illustrative drawings are given purely by way of example and are not to be taken in any way as limiting the scope or extent of the invention. The invention is further described with reference to the following more detailed description of the invention with the accompanying drawings.

List of Drawings:

Fig 1 (PRIOR ART) shows some flying-lead EEG electrodes in appropriate places on a human head.

Fig 2 comprises a schematic view of an electrode array 200 and a head stage 201 according to the invention. A left channel and a right channel are shown here.

Fig 3 shows the layout of an example printed electrode array laid onto a flexible substrate and for use as a first signal path, and including a passive ("equivalent") circuit (the second signal path) mimicking the typical impedance of a patient.

Fig 4 shows the layout of another example printed electrode array also laid onto a flexible substrate.

Fig 5 shows a different version of artefact-detecting circuit including a motion sensor..

Fig 6. is a basic circuit in terms of analogue electronics, showing impedance measurement.

Fig 7. is a basic circuit showing use of an RF link which might pick up artefacts, between a headstage and a device.

Fig 8. Trace (with stable impedance) showing the temporal relationship between step changes in impedance and artefactual signals in a range of frequency bands from neonatal EEG recordings. Top trade: impedance. Second trace: differentiated impedance. Further traces: 5, 15, 25, 60, 80 and 95 Hz.

Fig 9. Trace (with unstable impedance) showing the temporal relationship between step changes in impedance and artefactual signals in a range of frequency bands from neonatal EEG recordings. As Fig 8.

In principle, this invention is devised to clean up a clinical electrophysiological signal such as an EEG from most or all artefacts (interference) by a process of separately collecting and recognising each kind of artefact as far as possible given that they may be of unpredictable origin, and then interrupting the clinical signal during the period of occurrence of the artefact. The invention thus provides a sensor for the detection of artefacts attributable to external or environmental noise, and takes or suggests appropriate action. Most Examples provided herein have a physically distinct channel (the second signal path) for sensing of artefacts, although one (Example 4 - impedance) merges an artefact-sensing signal with the clinical signal during amplification, and then separates the two on the basis of frequency bands. In contrast, most of the prior art assesses the clinical signal itself against a set of criteria and may decide that portions of the clinical signal are abnormal and should be deleted.

The separate path may be a replicated input channel sensing signals across a "dummy patient" or "equivalent load" placed between electrodes (Example 1) best placed adjacent to the skin electrodes applied to the patient, where it is in a position to collect some forms of interference collecting electromagnetic interference from the area including the patient and perhaps also (Example 2) triboelectric or microphonic signals impinging on signal cables connected to the clinical monitoring device. By analogy with Example 2, the invention when used with wireless channels to transfer signals from a patient to a device may include an "artefact channel" (Example 3) to collect wireless interference, whether electromagnetic interference or light waves. If the equivalent load is also in contact with the patient near an eye or the heart, physiological artefacts may be deleted.

This invention is particularly though not exclusively directed to use with / within EEG type apparatus known as a Brain Rescue Monitor or Brain Monitor (BM) as previously described by the inventors. Use of this equipment is characterised by the collection of EEG data from a mammal at risk of development of brain damage over a long period of from hours to days. The BM provides for automated inspection of the digitised records particularly in relation to calculated parameters such as (the upper) "Spectral Edge" - a frequency in Hz related to brain function and trends of brain function over time. At this time, the BM is mainly used with neonatal or pre-term infants under intensive care, but the same approach can be scaled for use with adult humans such as those undergoing open-heart surgery, or suffering from brain trauma, or can be used with animals.

By way of introduction, prior art EEG electrodes are shown in simplified format, applied to an infant head 100 in Fig 1. Two pairs of electrode assemblies 101 + 102 and 104 + 105 are placed over the parasagittal region/fronto-parietal-occipital cortex. Each is coupled via a flexible, shielded

cable to a connector 108. A ground reference pad 103 is likewise coupled to the connector 108. It will be evident that the flying-lead electrodes indicated in Fig 1 are likely to be placed wrongly and it is particularly useful in a long-term recording to have consistent placement if the electrodes must be replaced by different people during the recording period. In these illustrations the skin contact electrodes (eg 103, 105) are shown with slanted shading.

Note that the BM invention has always been capable of operating with one electrode pair on one side of the head although more reliable and useful results are obtained by monitoring both sides if possible. It will be evident to the skilled reader that this invention is not limited to the illustrated left pair and right pair of electrodes used together. Either pair on its own will suffice but we prefer to provide symmetrical pairs in our arrays (see below).

EXAMPLE 1

Fig 2 shows a block diagram of this form of the invention. Numeral 200 indicates the electrode array, 108 indicates a connector, and the dashed block 201 indicates an appropriate head stage amplifier, containing amplifiers 202X, optional frequency limiting circuitry (not shown), a multiplexer and analogue to digital converter 203, and a serial input/output interface 204 connected to a communications line 205 running to a suitably programmed computer. Within the amplifiers, 202L and 202R are standard signal (instrumentation) amplifiers connected to patient electrodes - the two pairs of patient skin (or sometimes subcutaneous) electrodes 101 with 102, 104 with 105, and 103 as a reference or ground electrode. 202AL and 202AR are also standard signal (instrumentation) amplifiers connected instead to the simulated impedances, A passive resistor matrix serving as an equivalent circuit is shown in duplicate; resistors 206L and 207L are connected to the inputs of a first amplifier and grounded by resistor 208L, similarly resistors 206R and 207R are connected to inputs of another amplifier and grounded by resistor 208R, in a "Y" configuration with one resistor included in each limb. Optical isolation is desirable at the interface, in order to avoid passing currents through the patient. The communications line is at present an RS-232 protocol cable, but may instead conform to other protocols even those employing wireless links. It must be realised that the particular head stage approach shown here is not an essential part of this invention; any bioelectric amplifiers capable of processing signals of the EEG type (in terms of noise level, input current, CMRR rejection, amplitude and frequency) will do. Indeed, the amplifier used to amplify the artefacts may be of a lesser quality, use AC coupling, etc.

There are several parts to the Example; there is an EEG electrode array 200 constructed upon a flexible base by a conductor-printing technique (as is known in the art) but also including a "simulated patient" made of an "equivalent circuit" carried upon the flexible base and connected to similar amplifiers and signal processing means to that used for the EEG itself (201), and there is a signal processor 210 (here, placed within the BM) for acting on the EEG signal whenever supra-threshold signals appear from the simulated patient. It will be appreciated that the cost of

duplication is minimal when flexible printed-circuit manufacturing techniques are used in construction.

Various flexible electrode arrays (200, with similar versions in Fig 3 and Fig 4) are primarily intended to provide bilateral recording of the EEG from skin electrodes applied to the cranium of a neonatal or pre-term infant. The array is adapted by size and shape in order to be positionable over the areas of the brain most likely to exhibit pathological changes and is intended for long-term use over some days. Dimensions of an example array (Fig 3) for the above purpose is 22 cm from the connector 108 to the far edge of the reference electrode 103, and the centres of the skin electrodes 101 and 104 are 8.5 cm apart, though even within this specific application sizes may be varied. Arrays for use in adult humans or with other mammals may have other appropriate dimensions. As shown in Fig 3 the array includes two pairs of symmetrical pads (electrodes 101 with 102, and 104 with 105) intended for use with the usual balanced (instrumentation-type) low-level amplifiers. The contact areas of the pads are preferably made of chlorided silver as is known in the art, although other conductive materials may be used such as graphite, gold, or stainless steel. In the preferred form of the invention a "HydroGel" (TM) patch covers each electrode 101, 102, 103, 104, and 105. Each pair of pads is placed to a side of a central axis and at an angle of about 45 degrees (as illustrated). The reference (ground) electrode of a similar material is at the end of an extended conductor on a long flexible strip 305 along the central axis. All conductors on the flexible substrate are shown here as black lines such as 306, leading to reference pad 103 which has a sticky tab 301 at its end.

The preferred material for the substrate is polyethylene terephthalate ("Mylar" TM) although other substances suitable for use in flexible printed circuit manufacture may be used. (We are now considering woven cloth substrates which may be flexed in two directions, and insulated multi-strand copper wire in conjunction with robotic assembly). The conductive strips are preferably made of silver, which is not expensive. Copper tracks result in a stiffer electrode array. The conductive strips terminate in a row of strips 108 aligned with the contacts of a connector. Conveniently the connector comprises part of a head stage amplifier 201, locatable close to the patient and including all the analogue amplification equipment and analogue-to-digital conversion devices needed for operation of the BM so that a conventional serial cable link (205) carries data to the computer processor itself.

Optionally, an array of this type may also include the sensing elements for an artefact sensor as described elsewhere in this specification. The extra contacts used in this example are linked to the equivalent circuit mounted upon the substrate and as described below. This electrode array may also or alternatively include devices for sensing other modalities, such as temperature, or a patient motion sensor. Patient motion, whether caused by nursing or by the patient's own activity often results in either electromyogram (EMG) signals from nearby muscles, or artefacts caused by

electrode contact variations or "microphonics" in cables. Also optionally, a transcranial optical density measurement (or trend) sensor for example may be provided as an emitter and sensor (one on each side) of pulsed or steady visible or infra-red light for trans-cranially sensing blood flow. Hydrogel being transparent and clinically acceptable is also a useful optical coupling medium.

At present we intend to normally provide separate left and right EEG channels as well as separate left and right artefact channels each with an equivalent circuit. It may be sufficient to use just one artefact circuit and optionally place other sensors in the vacant space on the other side, but this depends on the frequency of use of unilateral rather than bilateral BM monitoring in clinical practice. Although separate electrode arrays might be sold for left side only, right side only, or both sides applications it is easier to supply one kind of stock item with both sides present, and amputate unnecessary material on the spot.

An outer electrical ("Faraday") screen (209 in fig 2) of conductive silver for example may be applied over the "cable" part 107 of the electrode array and along each arm up to the position of the resistors (206L, 207L, 208L), which allows higher resistor values to be used, and a foam covering (not shown) may be applied over the entire object except the electrode contact surfaces so that the device seems softer and is less likely to cause trauma.

Fig 4 shows a different example configuration of electrode array (at a different scale to Fig 3) having similar sensing pads (101, 102, 104, and 105 with reference 103) on a flexible substrate. The on-substrate tracks between the connector 108 and each pad are not shown for clarity. An artefact rejection circuit or at least part thereof, as previously described, is preferably mounted upon the substrate as in the case of example 3. When applied on to a cranium, the reference electrode 103 would be placed medially towards the forehead while the pairs of sensing electrodes (101 with 102, 103 with 104) would lie on each side of the median line over an area of the brain to be monitored. In the case of an adult human undergoing a procedure believed to include a risk of causing vascular occlusion in the brain (such as open-heart surgery) the sensing electrodes may be best placed over the areas of the brain supplied by the middle cerebral arteries, and the dimensions of the electrode array would be adjusted to suit. These particular designs do not show any means to collect eye-related natural artefacts, mainly because our preferred recording sites are well back on the head from the forehead.

The preferred equivalent circuit comprises a passive set of resistive elements mounted upon the substrate and sharing a similar geometry of connecting elements to those used by the active disc electrodes 101, 102 and 104, 105, so that external sources of artefactual signals have a similar effect on both the artefact channel and the patient signal channel. The equivalent circuit is similarly prone to picking up mechanical and electrical interference in the same way as the EEG electrodes. It may be preferable to place the equivalent circuit at the ends of the sticky tabs 302 and 303 rather than medially as shown.

The example equivalent circuit (see Fig 2) comprises a "Y" or branched circuit. Two arms of the "Y" are each connected between an input of an instrumentation amplifier through a resistor (206L and 207L) to a common point; the common point being connected through a third resistor 208L to the ground/reference conductor. (Parts 206R, 207R and 208R are part of the opposite side equivalent circuit). "Selected" means that we predict likely actual patient impedances and provide similar values for the resistances, though it appears preferable to use higher values; perhaps 4 times the expected patient impedance of about 10K ohms (soon after application) both because the circuit becomes more relevant when the electrode dry out or become less effective over time, and because the lead pickup effect becomes more effective as a capacitative pickup if the terminating resistors are increased in value. The equivalent circuit is placed in a dedicated area included in the layout of the disposable electrode array (Fig 3) to be placed on the patient's head. Typical preferred values for resistors 206, 207 are about 27K (K = thousand ohms), and typical values for resistor 208 are from 100K to 200K ohms.

The preferred embodiment uses surface-mount resistors attached to pads in the usual way (using low melting point solder, or conductive paint) and the predominant electrical property is hence purely resistive though the entire circuit includes some capacitance to ground. Because some electrode material surfaces exhibit non-ohmic properties, the invention allows for the resistive elements to be supplemented with either or both capacitative and inductive elements in order to more closely simulate a patient's impedance at various AC frequencies. For example stainless steel tends to behave as if there is a series capacitor between the electrode and the patient, particularly at low frequencies. This may be due to the thin film of oxide that forms on any surface of that metal. The actual supplementation that is likely to be useful depends in part on the frequency band selected for operation of the subsequent amplifiers. More complicated networks than those described here may for example include several resistors in series with capacitors bridging some of them, in order to replicate the behaviour of particular types of skin electrode.

A variation of the above artefact amplifier circuit is shown in Fig 5. This circuit 500 is intended to enhance differences between signals at the input whereas the previous amplifier was constructed to be as symmetrical as possible in which case those signals picked up along the lead 107 (fig 3) might be the predominant type of artefact signal passed on for processing. As before, the instrumentation amplifier 501 is itself preferably mounted remotely from the parts 502-507 which are preferably upon the electrode array.

The amplifier block 101 is preferably an instrumentation-type amplifier capable of rejecting common-mode signals, (although a single-ended amplifier might suffice, with a rearranged circuit). In this circuit, the non-inverting input includes two resistors 502 and 505, preferably together having the same value as the resistor 503 in the inverting input. Resistor 508 mainly serves to provide a return path for input bias currents. One asymmetrical input is an unscreened capacitative

pickup plate 504, in dimensions like an electrode pad 101 (etc) but coated with insulation and not in contact with the patient, is attached to the resistor chain and in turn to one side (in an asymmetrical manner) of the instrumentation amplifier 500. This plate assists in collecting changing electric field signals such as from unscreened mains cables. Another asymmetrical input is an open coil 507 is optionally wired across the free end of the resistors in order to convert changing local magnetic fields into a differential input to the amplifier 501. Preferably the coil is shunted with a resistor (not shown) in order to reduce any undesired resonance effects. The orientation of this coil (perhaps 20-50 turns) is preferably one that best collects flux from those changing magnetic fields that also cause interference within the patient/electrode/cable circuit. Optionally, a permanent magnet 506, perhaps made of a ferrite, is resiliently mounted in or beside the coil 507 so that mechanical movement of the magnet in relation to the coil generates a differential input. That movement may occur if the electrode array is accelerated. Optionally an omnidirectional variant of the coil (and movable magnet) can be used rather than the simple example described. As a result of the deliberate asymmetry, the output 509 of the amplifier is more likely to carry derivatives of electromagnetic or mechanical artefacts, and the amplifier may be operable at a lower gain and consequently in a more reliable way.

The instrumentation amplifier used for amplifying artefacts is located alongside the amplifier used for EEG signal processing and is provided with similar filters for the setting of passbands in terms of low and high frequencies and is typically run at the same gain. Preferably the EEG amplifier is operated so that it does not enter saturation as a result of amplified DC offset levels. (The artefact amplifier should not experience DC offsets, being kept apart from electrochemical effects).

In theory there are at least three ways to make use of the output of the artefact channel, although some are more practical than others. One is to use conventional analogue or (after digitisation) digital signal processing technology to subtract any small level artefact signals present in the artefact channel from the real EEG signal, on the basis that the signal channel comprises signal + artefact while the artefact channel is artefacts only. (By "small level" we mean, for example, that the signals are not so large that they cause amplifiers to saturate. They are represented at the amplifier outputs in a linear manner). This depends on the correct phase always existing.

The second approach, more suitable for large level artefact signals is to use the artefact signal to control a gate in order to interrupt the data signal during the presence of the interference. Gating may be carried out in either an analogue (as with a sample-and-hold module), or in a digital signal processing stage.

The third approach which has been adopted within the BM 210 is a kind of gating process. It comprises additional software processing in or about the existing BM process for handling the EEG signals in (typically) four-second blocks. The software tests a number of parameters as shown in the table below. This approach is compatible with simultaneous use of other methods to sense error

conditions such as the saturated amplifier or the disconnected electrode. In summary the preferred method treats data to be deleted as a missing data point that is interpolated using medians or averages, or with large blocks rejects an entire block and flags it if any problem is detected during a four second epoch. The artefact sensing approach described herein will not see artefacts developed within the patient (eg heart or voluntary muscle activity) or within the patient signal processing chain (eg amplifier saturation) as signals within the artefact channel.

(In addition to an artefact amplifier as described above, an electrode assembly may include a motion sensor to detect physical movements of the electrode sensor array, such as when the patient moves, the incubator is bumped, or nursing care is being given. Examples of possible motion sensors include: the low-impedance group such as magnet & coil assemblies, (possibly connected within the passive resistor array between resistor 206x and 207x so that signals appear as artefact signals), the high-impedance group such as electret microphones and piezoelectric devices, and the active group of integrated circuits for example including structures capable of detecting movement such as accelerometer devices. A circuit path is not shown in Fig 2, nor is a motion sensor shown in Fig 3. Because the electrode array of silver and including a resistor array costs only about NZD 1.50 and is essentially disposable, a motion sensor should be preferably selected with cost versus benefit in mind).

Example 2 - Triboelectric (microphonic) artefacts.

When cables are touched or bumped, triboelectric or microphonic effects which may be caused by electret-type phenomena of fixed electric charges within the insulation can cause artefacts. Given relatively long signal cables in neonatal intensive-care units, to reach into incubators, this type of effect is relatively common. The appropriate method for controlling this form of artefact is to take care to extend the duplicated electrode assembly with a closely similar electrode cable assembly made of the same kind of cable materials running in parallel with the signal cable, and treat any signal arising from the duplicate cable as an artefact. This will also collect any electromagnetic interference that would be collected by the signal cable. Software recognition may be largely based on reasonably identical signals in both the first and second signal path.

In order to remove the relatively long signal cables required within neonatal intensive-care units, to reach into incubators and make contact with infant craniums, we will use a short-range radio-frequency link between aerials 703 and 704 originating at a battery-powered head stage including amplifiers 701A, 701B and two-channel multiplexed battery-powered transmitter 702. This will simplify the tasks of nursing the very delicate neonates and reduce any trauma that body movements may cause. One of the standard digital short-path formats will be used. The inherently low power of a compact, battery-powered transmitter makes the signal path relatively prone to interference 704. In order to detect interference and minimise any effects we propose to duplicate the signal path from amplifier 701A connected to electrodes 101 and 102 with a second channel from amplifier

701B connected only to passive components 206L, 207L and 208L, and sample the second channel (608) as received by receiver 706 for any activity above a predetermined threshold. Any such activity will be regarded as artefact signals which will be used to control a gate 604 via threshold-sensitive switch (window comparator 603) as previously described so that the EEG output at 708 is as defect-free as possible. Again, a display 606 may be included to show an operator the extent to which artefacts are being detected, or in a more sophisticated digital version, (this Figure being only a simplified version using the conventions of analogue electronics) to indicate the cause and likely cure of artefacts. In the case of digital wireless, a second channel may be implemented by procedures well-known to those skilled in the art such as time or frequency multiplexing.

Electrode impedance is not a constant. It may rise as the hydrogel dries out, if the electrode is partly detached, if the skin may sweat or desquamate, or other changes occur with time. Impedance is liable to change a lot if the patient is lying on or pressing against a skin electrode. (It should be noted that needle electrodes exhibit worse electrical connection properties such as that the impedance is more likely to change than chlorided silver gel electrodes. Typical needle electrode impedances are about 100K ohms as against 10 K ohms, and the oxide on the stainless steel surface causes non-linear resistance effects at low voltages. They are more affected by patient movement).

In particular we have discovered that impedance variations, especially those that change quickly, are accompanied by signal transients. Figs 8 and Fig 9 illustrate two different patient records for each of which the top curve is of impedance Z, next is dZ/dt, then EEG recordings at 5, 15, 25, 60, 80, and 95 Hz, all against time. In Fig 8 the impedance trace lacks step changes and the EEG trace is relatively free of artefact. Note that different traces have different content as would be expected for an EEG recording. In Fig 9 the impedance trace includes many step changes and the differentiated impedance trace spikes can be correlated with spikes in all the frequency bands together and each of those cross-band sets is timed together with a step change of impedance.

These records indicate that it is appropriate to continuously measure the impedance of some or all electrodes, either as singles or as pairs of electrodes, which gives the ability to detect more, if not most causes of artefact with no more external hardware. The impedance trace exhibits a good signal to noise ratio, as does the differentiated impedance trace, indicating that they will usually be reliable indicators of artefact.

These records also indicate a further way to infer the presence of an artefact, which is to take signals from several frequency bands of EEG (such as all those available above 25 Hz) and assume that any spike common to all those bands indicates an artefact, which may be blocked or deleted from the channels of interest extending up to (usually about) 25 Hz. The necessary logic may be put into effect by a software routine. The traces examined do not separately show a very good signal to noise ratio although that may be improved by summation. Spikes having this origin may not occur with equal magnitude in all frequencies, hence it would be better to look for large spikes over a

certain threshold in for example any 4 out of 6 frequencies measured. By "large" we presently propose a change in signal strength of greater than 2.00 (200%) for 4 out of the 6 measured frequencies (5 Hz, 15 Hz, 25 Hz, 60 Hz, 80 Hz and 95 Hz). In particular the 80 Hz and 95 Hz will be very important since we do not normally expect to see any signals within that frequency range. To stab in the dark, what I would do is invalidate the data if the change in the signal amplitude exceeds 10% for 4 out of the 6 frequencies we're measuring. Undue relaxation of these criteria may lead to rejection of seizure spikes, which is undesirable and is why we tend to avoid data analysis itself as an indicator of artefacts.

Also, the presence of an artefact in those frequency bands which is not also present in the channel derived from the passive or equivalent resistance input strongly suggests that the artefact is caused by impedance changes rather than an external electromagnetic transient.

Fig 6 shows the principles of impedance sensing. It should be noted that the diagram illustrates the principle of the invention in terms of analogue electronic modules, whereas many of the functions are likely to be realised in software during signal processing. A sine wave of a fixed frequency perhaps in the 35-45 Hz range and of fixed voltage (5V) is generated within functional block 602 and coupled to the patient electrodes 101 and 102, either singly or in out-of-phase pairs through a high value resistance (610, 8.2 Megohms) and a small capacitance (611, 10 picofarads) thereby providing a small and safe constant-current source which will not normally interfere with EEG collection. The resulting amplified signal, the level of which is dependent on the inter-electrode impedance, is separated from the EEG signal by means such as high-pass filtering with capacitor 607 and synchronous rectification within module 602, and its level is assessed. (Module 602 may be a Signetics NE 5521 or equivalent). Whenever the level changes rapidly the EEG signal is interrupted. In this illustration we use a coupling capacitor 608 to pass only rapid changes to an input of a window comparator 603 the other input of which is connected within a voltage divider network so as to change state to active whenever the input signal exceeds a small absolute amount - as is well known to those skilled in the art. The comparator output when active causes a deletion circuit 604 to enter its "delete" mode. A preferred analogue deletion circuit is a sample and hold circuit in which the "hold" function serves as a deletion mode. As shown by the coincidence between electrode change and artefacts in Fig 8, this process should always trap an artefact signal so that the EEG output presented at output 612 is less contaminated by artefacts than previously. The selected sine wave frequency is above the used range of EEG signal frequencies and where more than electrode is being measured, a different frequency is used in each different circuit.

The comparator output may also be taken to a display device 606 used to indicate to an operator how frequently the electrode impedance is altering in a significant way, and in general to indicate the condition of the electrode array, which is a useful advantage. Indeed, impedance and equivalent

electrode monitoring are seen as important in data validation, such that the equipment should be prevented from operating with disposable electrodes incapable of providing for these tests.

Devices 603, 604, and 606 at least may be replaced by software routines within a software version of the device, for example as part of a spectral edge detection module for the Brain Monitor. That improvement permits a greater range of criteria to be taken into account, as shown in the following non-limiting table which shows some of the criteria taken into account at the Data Validation step in current software for the BM. Criteria could be expressed in absolute or in relative terms.

Data validation criteria include:

Parameter	*Criteria for rejection*
1. Absolute electrode impedance	< 500 ohm or > 15 K ohms (assuming silver).
2. Change in electrode impedance	> 20% change from previous epoch
3. Noise floor from equivalent circuit, plus amplifier contribution.	> 0.5 microvolts in 0.5 to 20 Hz band.
4. AC mains supply noise ("hum"; 50 or 60 Hz or harmonics) Usually in all channels.	> 50 microvolts p-p
5. DC saturation of preamplifier	If saturation is detected.
6. Input clipping	If clipping is detected.
7. EMG noise in the EEG signal	> 1 microvolt (25-35 Hz band).
8. EEG intensity	> 500 microvolts or < 2 microvolts (lower limit does not halt processing)
9. Hardware fault	If a hardware fault is detected.
10 Movement sensor activity (if sensor exists)	If patient movement is detected.
11. Presence of periodic interference eg at 15 Hz	Reject if severe, and raise alert re. respirator.
12. Presence of ECG (EKG)	Reject if severe, check impedance, guard against regarding this as seizures.

In our present brain monitor, the software alters the operator's control panel display in accordance with the fault detected, if any, and displays the percentage of 4 second epochs rejected per minute. We consider that less than 15% is satisfactory, between 15 and 50% is a minor problem, and 50% or more is a serious problem (We do not use needle or screw type stainless-steel electrodes, which are noisier). The software is preferably capable of producing at least one advisory message to a user when the likely presence of at least one artefact is established. This advisory message can comprise one or more of (a) naming the type or source of at least one artefact, or (b) the magnitude of at least one artefact, (c) the total artefact magnitude and possibly (d) the option to remove the part of the signal or signals attributable to artefact(s). Use of helpful and/or advisory displays is in accord with the intention that the machine can be operated by persons not skilled in collecting EEG recordings.

Ways to determine in software where the origin of artefact signals may be found, so that a remedial message can be put on a computer screen, include the following elimination process.

1. Fluctuations in electrode impedance but nothing in the equivalent resistor channel suggest electrode movement. For mitigation, reposition patient's head or sensors.
2. Fluctuations in data, and in the equivalent resistor channel (without electrode impedance) suggest triboelectric interference is being mechanically introduced into the lead (or radio interference is present in the radio link). The frequency content of the equivalent resistor channel may be helpful. Lower frequencies are more likely to relate to movement artefacts etc and higher frequencies suggest interference such as electrocautery.
3. Detection of periodic artefact signals such as ventilator hum, heart activity, or breathing movements may be based on frequency measurements.

Any one of the criteria in the above table can cause rejection of the incoming signal.

Usually the computer programme that implements the above decision tree will substitute the most recent good epoch for a rejected epoch so that a consistent set of data emerges for subsequent or on-line analysis.

VARIATIONS

Other kinds of clinical neurophysiology equipment, fetal electrocardiography equipment, and the like can be modified, perhaps at the time of manufacture, so that an amplifier and filtering chain preferably identical to that used for the clinical signal of interest is available for use as an artefact channel. A "patient-equivalent" circuit can be developed as appropriate for use against the patient and with similar leads, and artefact rejection means comprising either the subtraction or the gating types (or a combination of both) can be provided.

For example an electromyogram procedure used in physiotherapy or sports medicine is particularly likely to be affected by motion-induced interference.

While the apparatus as shown and described herein assumes that skin surface electrodes for external use, it is possible that subcutaneous electrodes (as used in Europe) may be used instead. Nevertheless, the principles of the invention still apply.

In the embodiments described, facilities for varying the gain of the artefact channel amplifier were not considered, because changing the numerical constant used for rejection amounts to much the same.

If bandwidth in the head stage to BM link is a problem, the artefact channel may be converted into a presence/absence digital form within the head stage hence substantially reducing the volume of data sent. to the BM. A threshold may from time to time be programmed into the head stage from the BM, using the radio link - if it is bidirectional.

COMMERCIAL ADVANTAGES

The invention provides a simple, relatively cheap, user-transparent apparatus and method for reduction of the total content of artefacts within a signal collected from a patient. In particular the invention is capable of detection and rejection of externally generated artefacts.

An advantage of extensive monitoring of artefacts is that the electrode impedance status itself may be reported to a person so that electrodes can be replaced or re-coated as required before the connection fails completely.

Artefact rejection amounts to a kind of self-test function, going beyond the apparatus itself, and provides a very good confirmation of a functional input and patient lead assembly.

The invention therefore enhances the reliability of data collected from a patient and so increases the relationship between information gleaned from the data and clinical procedures undertaken in response. In particular the information enhances the reliability of a brain rescue monitor used to monitor the activity of a patient's brain over possibly a long period.

The invention becomes more relevant for worse affected patients such as those with very low brain activity. Finally, it will be understood that the scope of this invention as described and/or illustrated within this provisional specification is not limited to the preferred embodiments described herein. Those skilled in the art will appreciate that various modifications, additions, and substitutions are possible without departing from the scope and spirit of the invention as set forth in the following claims.

WE CLAIM:

1. A device for assessment of the status of a mammal using electrophysiological signals developed within the body of the mammal; the device including in functional connection a first signal path including at least one electrode, a first electrode circuit, a first electrode - amplifier coupling means, a first signal amplification means, a first signal processing means, and an output means for presenting a useful output to an assessor, ***characterised in that*** the device provides means for rejection of at least some interfering signals likely to interfere with the electrophysiological signals, the rejection means including a second signal path capable in use of continuously collecting interfering signals; the second signal path including a second electrode circuit, second electrode - amplifier coupling means, second signal amplification means, and means for interruption of the first signal path prior to presentation at the output means, thereby deleting probable interfering signals from the first signal path so that the output may be relied upon to a greater extent as a true indication of the status of the mammal being monitored.

2. A device as claimed in claim 1, ***characterised in that*** the device is particularly adapted for monitoring, over a long period, electrophysiological signals developed within the brain of the mammal so that the status of the brain of the mammal may be presented to the assessor.

3. A device as claimed in claim 1, ***characterised in that*** the second signal path comprises means capable in use of detecting electromagnetically radiated interfering signals likely to interfere with the electrophysiological signals, the second signal path is substantially electrically isolated from the body of the mammal and includes at least one selected electrical component connected to an input of a second signal amplifier means; the at least one component being selected so as to simulate a typical electrical impedance like that of the first electrode circuit by the body of the mammal, when being monitored, and second electrode - amplifier coupling means used to couple the second electrode circuit to second signal amplification means, the output of which is connected to signal removal means capable of interrupting said first signal path during the occurrence of said electromagnetically radiated interfering signals so that likely artefacts are deleted from the output of the device.

4. A device as claimed in claim 3, ***characterised in that*** the second signal path includes a second electrode circuit placed in proximity to the first electrode circuit, thereby comprising an electrode assembly.

5. An electrode assembly as claimed in claim 4, ***characterised in that*** the electrode assembly, including the at least one electrical component, is supported upon a flexible substrate material.

6. A device as claimed in claim 1, ***characterised in that*** the first signal path employs a cable as the first electrode coupling means, the device including a second signal path capable in use of continuously collecting interfering signals of mechano-electrical (triboelectric) origin, likely to

interfere with the electrophysiological signals, the second signal path including a second electrode circuit placed in proximity to the electrode assembly and coupled through a substantial replica of the first electrode coupling means placed in close proximity to the first electrode coupling means, to a second signal amplification means, coupled in turn to a signal removal means capable of interrupting the first output during the occurrence of said signals of mechano-electrical (triboelectric) origin so that likely artefacts are deleted from the output of the device.

7. A device as claimed in claim 1, ***characterised in that*** the first signal path employs wireless electrode-to-device coupling means as the first electrode coupling means, ***characterised in that*** the device includes means to detect electromagnetic interference likely to interfere with the electrophysiological signals, the detection means including a second electrode circuit placed in proximity to the electrode assembly and coupled through a substantial replica of the first wireless electrode coupling means to a second signal amplification means, coupled to a signal removal means capable of interrupting said first output during the occurrence of said signals so that likely artefacts are deleted from the output of the device.

8. A device as claimed in claim 1; the electrode assembly having in use an electrical impedance when connected to the body of the mammal, ***characterised in that*** the assembly includes (a) means for continuously monitoring the electrical impedance of at least one electrode within the electrode assembly, (b) means to identify an abrupt change in the or each electrical impedance as an indication of likely concurrent artefact, and (c) means to interrupt the bio-electrical signal at about the time when an abrupt change in the or each electrical impedance occurs, so that likely artefacts are deleted from the output of the device.

9. A device as claimed in claim 8, ***characterised in that*** the means for continuously monitoring the electrical impedance comprises injection of a small alternating-current test signal into the circuit at a a higher frequency than that of the electrophysiological signals, the second signal path comprising a higher frequency band of the first signal path, the second signal path providing selective amplification of signals at the test frequency, identifying any abrupt change in the amplitude of signals within the second signal path, and using any identified abrupt change as a command to interrupt the first signal path so that likely artefacts are deleted from the output of the device.

10. A device as claimed in claim 1 ***characterised in that*** the device provides signal processing means in the form of digital computation under control of a software programme, the programme including means to at least partially recognise one or more forms of artefact signal according to criteria, and to (a) interrupt the first signal path during occurrence of said artefact signal, and (b) provide upon a display device information alerting an assessor to the nature and extent of the artefact signal, so that a relatively untrained assessor may take steps to reduce and adverse effect of the artefact signal.

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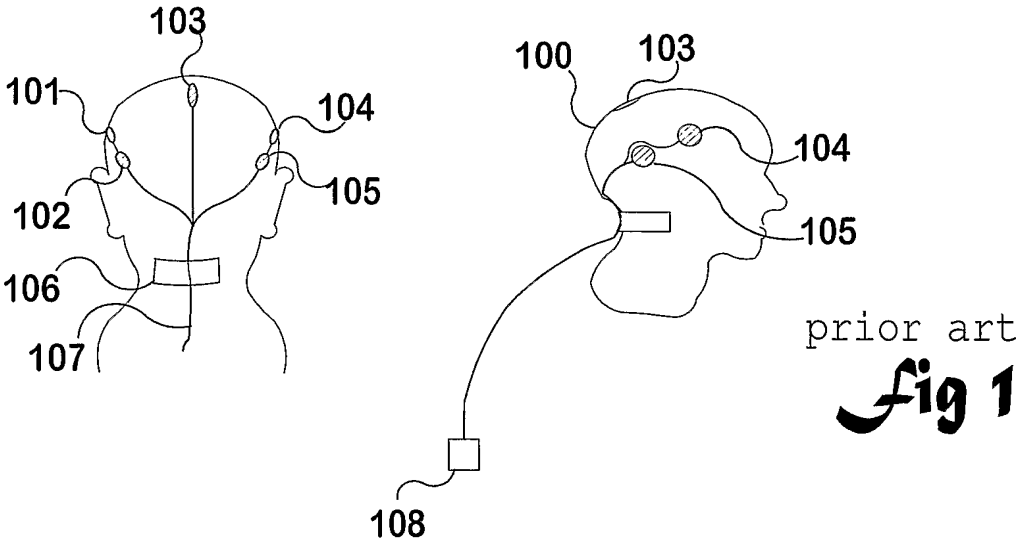

prior art

Fig 1

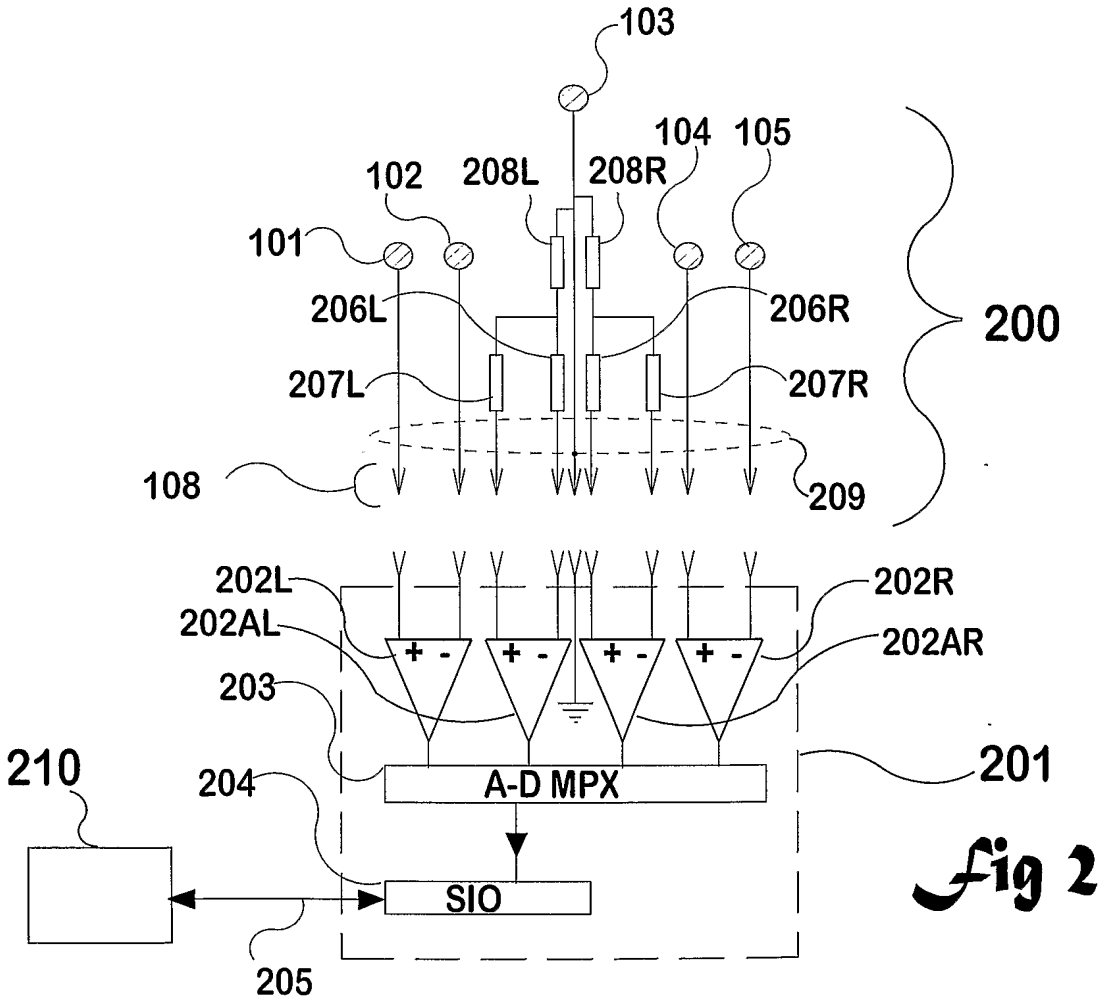

Fig 2

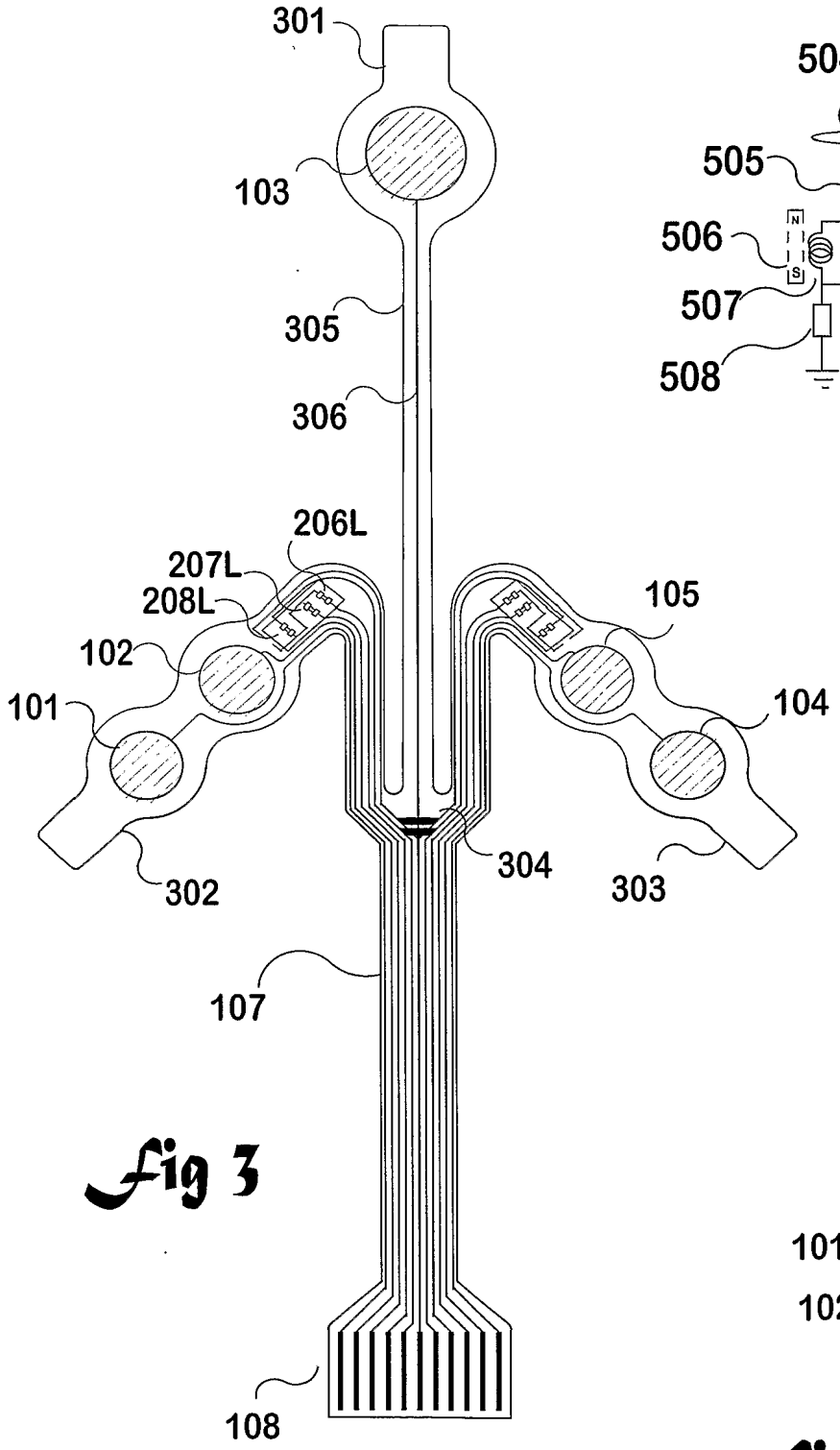

Fig 3

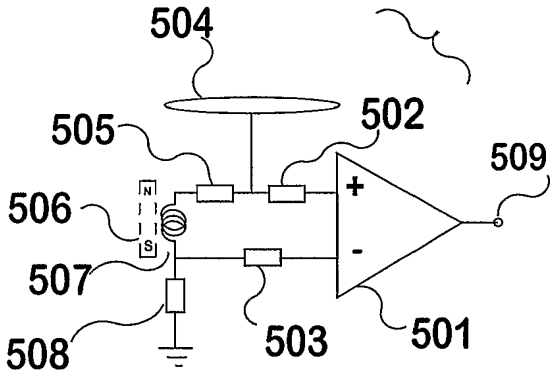

Fig 5

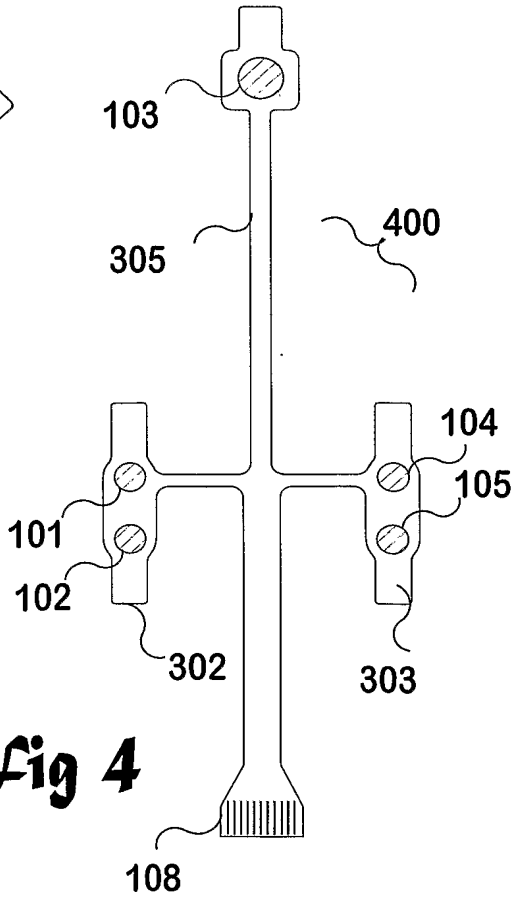

Fig 4

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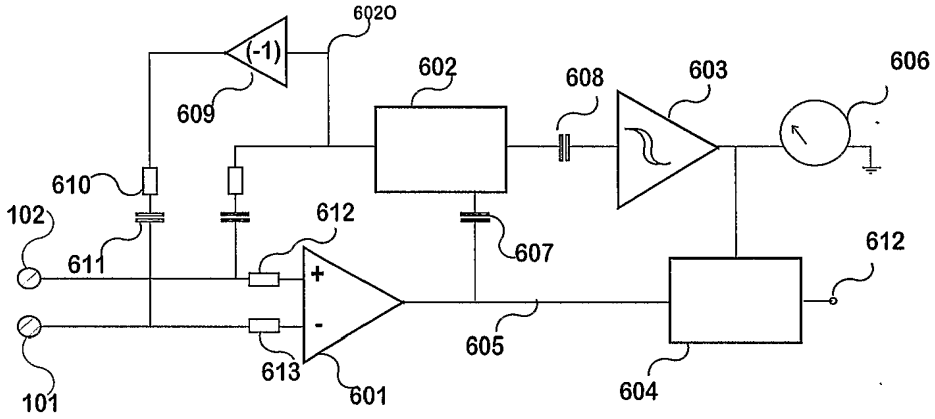
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Fig 6

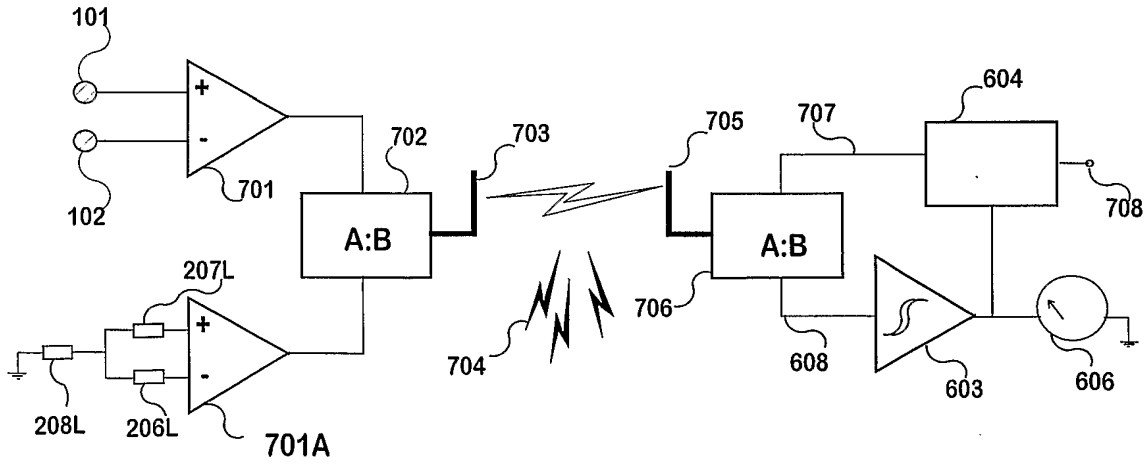
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Fig 7

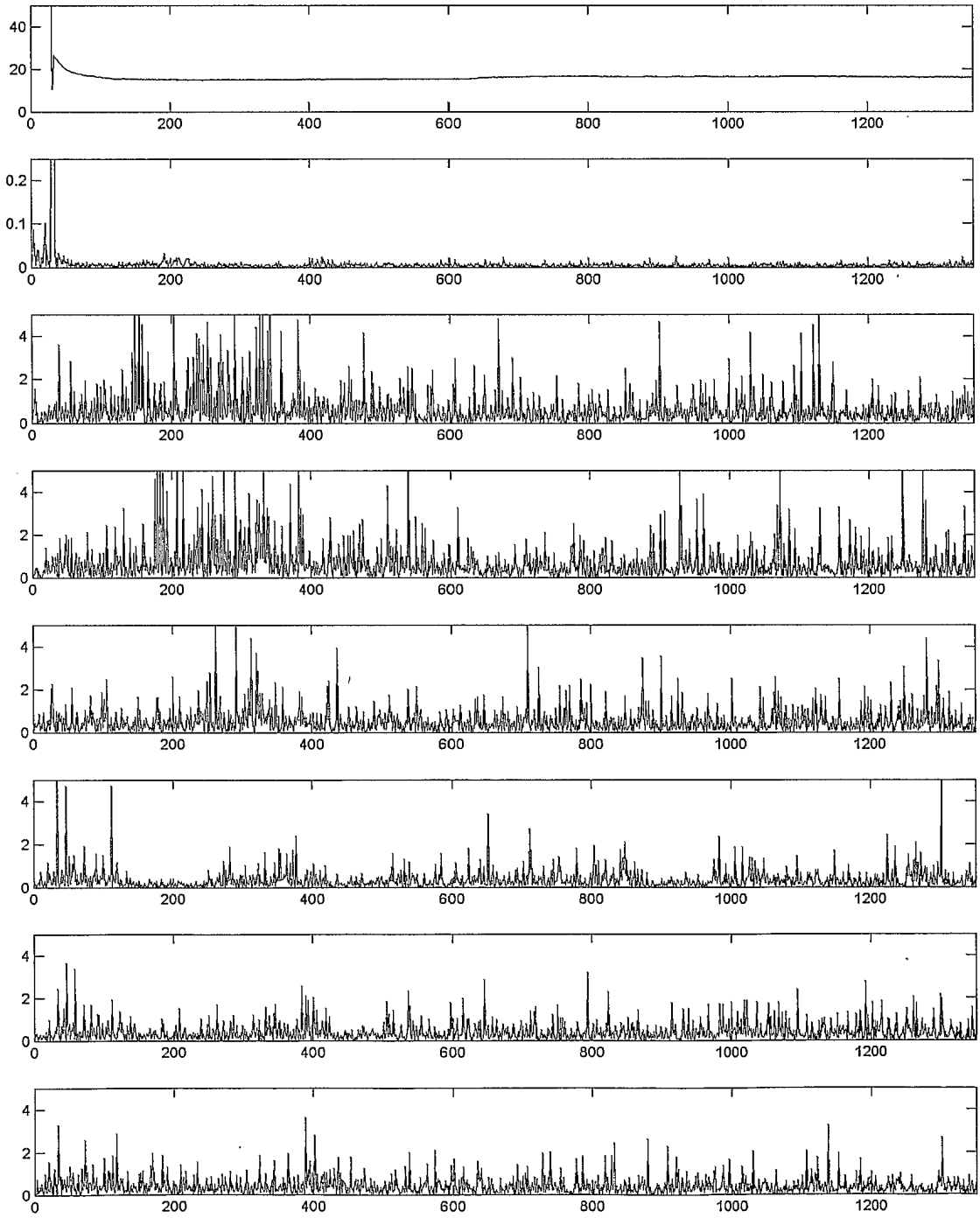
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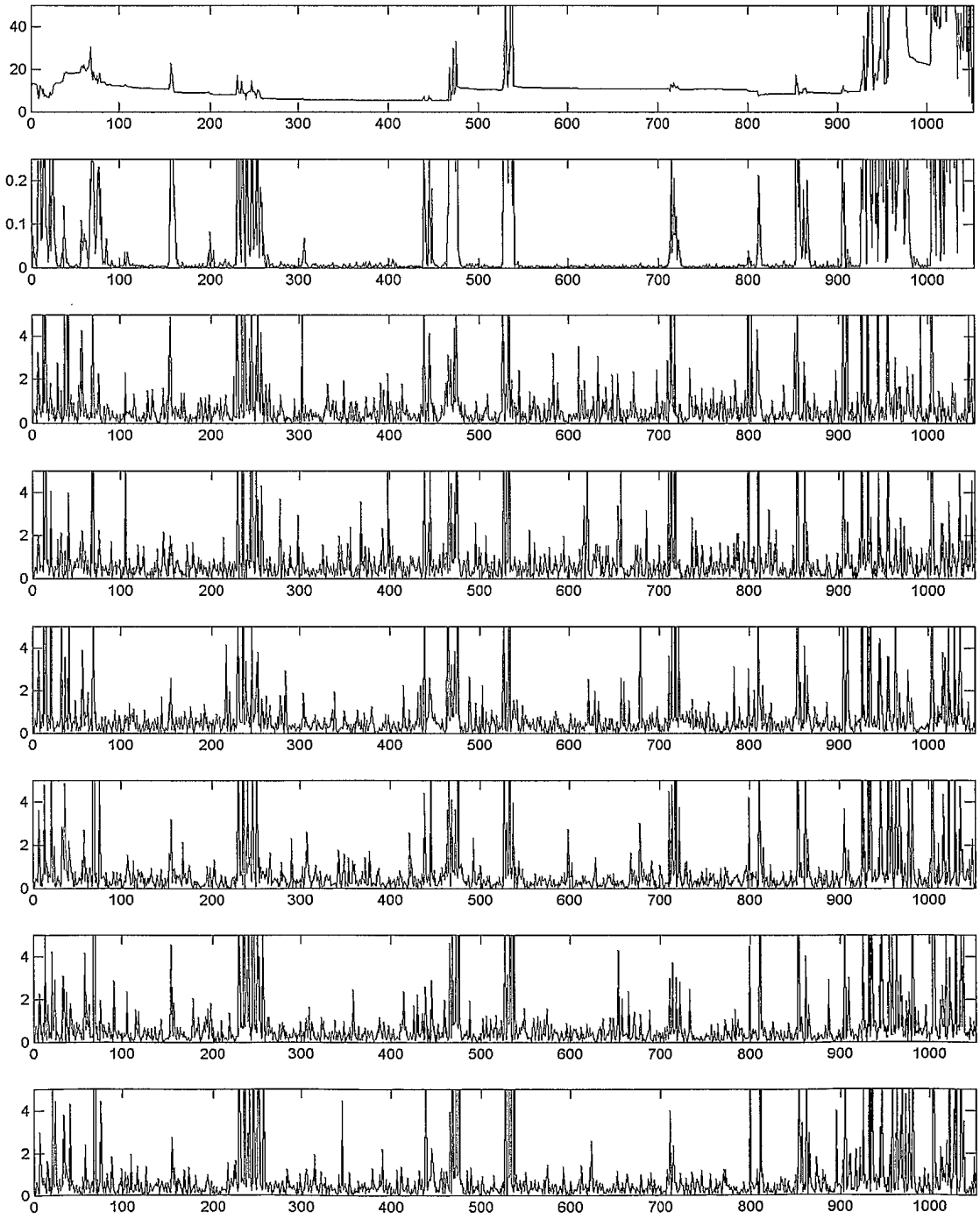
Fig 8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4
2
0
0 100 200 300 400 500 600 700 800 900 1000
4
2
0
0 100 200 300 400 500 600 700 800 900 1000
4
2
0
0 100 200 300 400 500 600 700 800 900 1000

Fig 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NZ03/00124

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]: A61B 5/0476

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Refer to electronic databases consulted below

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DWPI +keywords: EEG, noise, cancel and similar terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,678,559 A (DRAKULIC) 21 October 1997 Abstract	1-8, 10
X	EP 1 050 270 A1 (BRUKER MEDICAL SA) 8 November 2000 Abstract	1, 3-8, 10
X, P	WO 03/000128 A2 (ASPECT MEDICAL SYSTEMS INC.) 3 January 2003 Abstract	1-8, 10

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 August 2003	14 AUG 2003
Name and mailing address of the ISA/AU	Authorized officer
AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	**SUE THOMAS** Telephone No : (02) 6283 2454

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NZ03/00124

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X, P	US 6,487,295 B1 (LOFGREN et al) 26 November 2002 Abstract	1, 3-8, 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NZ03/00124

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member			
US	5678559	NONE			
EP	1050270	FR	2793131	US	2003114768
WO	03000128	NONE			
US	6487295	NONE			

END OF ANNEX